

The Energy Situation in Central Asia: A Comprehensive Energy Review Focusing on Rural Areas

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Abstract: The northern part of the globe is dominated by industrialisation and is well-developed. For many years, the southern part of the world (South Asia, Africa etc.) has been a target of research concentrating on access to energy (mainly electricity) in rural regions. However, the Central Asian region has not been a focus of energy research compared to South East Asia and Africa. Despite plentiful domestically available energy resources, the energy supply in Central Asia is very unevenly distributed between urban and rural areas. Almost half of the total population of Central Asia lives in rural areas and there is a lack of access to modern energy services to meet primary needs. To analyse the energy situation (i.e., electricity, heating, hot water consumption, cooking, etc.) in rural Central Asia, this paper reviews residential energy consumption trends in rural Central Asian regions as compared to urban areas. Furthermore, the paper illustrates the potential of renewable energies in Central Asia. To perform the study, a qualitative comparative analysis was conducted based on a literature review, data, and statistical information. In summary, the presented article discusses the rural energy situation analytically and provides in-depth insights of Central Asian energy infrastructure.

Keywords: Central Asia; energy resources; rural energy supply; energy services; renewable energy

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1. Introduction

1.1. Background and Context

Universal access to affordable and clean energy access by 2030 is one of the goals defined in the United Nations' Sustainable Development Goals (Goal 7). To enable energy access, researchers have proposed several energy-related solutions to meet basic human needs, such as electricity, heating, cooling, clean cooking, etc., and in despite their work, billions of people are still deprived of even primary energy services [1–4]. Hence, universal energy access is considered as one of the most crucial targets among all Sustainable Development Goals.

Carrillo [4] identified that the issue of energy scarcity and energy security are especially critical for rural populations of developing countries. Also, Muhumuza et al. [5] recognised that provision of modern energy services remains a key problem and challenge for rural populations.

Research into energy security in the southern part of the world (especially South East Asia and Africa) has a long tradition, most of which focuses on electricity access in rural regions [6–8]. However, from the energy research point of view, Central Asia has received less attention than other Asian regions. Energy scarcity in Central Asia exists because of multiple dimensions including the geographical context, nature, environmental influence, and international factors [9].

Geographically, Central Asia is facing completely different energy situations as compared to the industrialised countries of the global north as well as the developing global south [10]. Central Asia is situated between the Caspian Sea in the west and China in the east and between Afghanistan in the south and Russia in the north. The region consists of the five different former Soviet republics called Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The basic statistics and demographics of the Central Asian countries are listed in Table 1, which helps to characterise the Central Asian republics from the socio-economic point of view.

Table 1. Key socio-economic indicators of the Central Asian countries in 2018 (data according to [11–15]).

Indicator	Kazakhstan	Turkmenistan	Uzbekistan	Kyrgyzstan	Tajikistan
Surface area in km ²	2,724,902	488,100	447,400	199,950	141,380
Population in million	18.2	5.8	32.95	6.3	9.1
Share of rural population in %	43	43	50	64	73
Gross Domestic Product in billion	USD 170	USD 40.761	USD 50.49	USD 8.0	USD 7.5
Gross National Income/capita	USD 7970	USD 6380	USD 2000	USD 1130	USD 990

Several geographical and geopolitical factors are unfavourable for economic development in Central Asia [16,17]. The Central Asian region is geographically distant from the foremost centres of world economic activity. Furthermore, all the Central Asian countries are landlocked with minimal transportation connections inside and outside their borders [18–20]. The limited connectivity between Central Asia and the outside world remains a major hindrance to expanding the trading and commercial sectors [16,21]. Hence, because of the limited economic activity, most of the Central Asian population make their living in the agriculture and forestry sectors [22,23].

Central Asia is a vast region (~4 million km² and has a total population of ~70 million), with a diverse range of geographical features and climates [24]. This includes high-altitude regions, a long-range of snowy mountains, sizeable and warm deserts, and plentiful water resources including two inland seas. Deserts mainly occupy the majority of the land area of Kazakhstan, Uzbekistan, and Turkmenistan. The major deserts in Kazakhstan (Kyzyl Kum and Taklamakan) have extreme temperature ranges with seasonal drought. The strong winds are responsible for dust storms in Kazakhstan which result in agricultural land erosion, and the same applies to the deserts in Turkmenistan and Uzbekistan [25–27].

On the other hand, water resources are an essential feature of Kyrgyzstan and Tajikistan. Both countries have extensive mountainous ranges including the Pamir mountain range (Tajikistan) and the Tien Shan mountain range (Kyrgyzstan). These elevated mountainous ranges (up to 7000 m) are responsible for the high-altitude characteristic and the cold climatic zone of these countries [28]. The major part of the mountain ranges is permanently covered with snow and glaciers. The glaciers are the origin of natural water resources which flow in different waterways (i.e., rivers, irrigation channels, water streams, etc.) in Kyrgyzstan and Tajikistan [15]. Downstream countries (Uzbekistan and Turkmenistan) are supplied with river water that is used for irrigation of agricultural fields from upstream countries (Tajikistan and Kyrgyzstan) [29,30].

Central Asia's climate is highly variable across the five countries and represents diverse topographical conditions. For instance, Kyrgyzstan has a cold climate and the majority of the land is covered with snow during the wintertime. However, Tajikistan's climate is mainly subtropical and semi-arid, with half of the country's elevations above 3000 m, while 80% of Turkmenistan area is flat desert [31]. Because of the mountain ranges in the east and southeast, winters are harsh and prolonged with a temperature range of −25 °C to 10 °C with a snow-covered landscape for more than half of the year. The summers across the Central Asian regions are generally warm to hot, with mean temperatures ranging from 10 °C to 40 °C [32].

1.2. A Framework of Energy Resources

Besides its unique geographical and climatic circumstances, Central Asia is endowed with abundant and diverse energy resources, such as natural gas, oil, raw coal, and plentiful untapped renewable energy resources, including hydro, solar, wind, and biomass energy [9,10]. Figure 1 indicates the available natural energy resources by country.

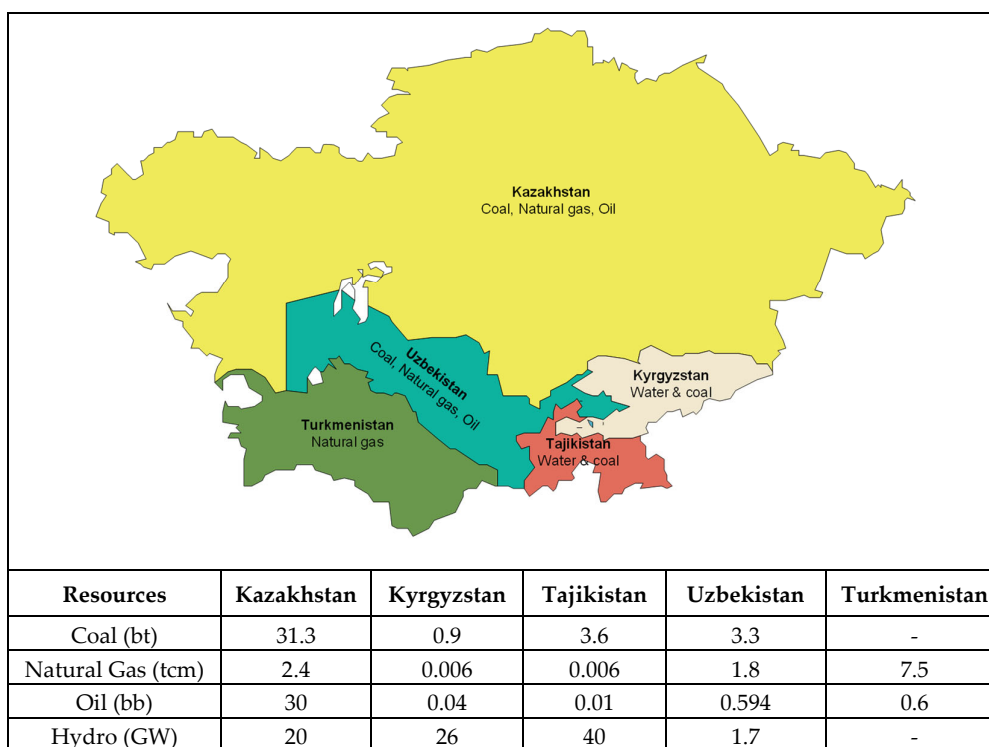


Figure 1. Available energy resources by country (bt = billion tons, tcm = trillion cubic meters, bb = billion barrels, MW = megawatts) (data according to [9,10]).

Kazakhstan is the largest and wealthiest country within the Central Asian region and possesses large oil and coal reserves. Uzbekistan is a significant fossil fuel producer in Central Asia, while Turkmenistan is also a significant energy player in Central Asia, as it has significant natural gas resources and an established thermal power sector [33]. In contrast, Kyrgyzstan and Tajikistan are the smallest and most impoverished countries in the region; however, the very large hydropower resource is concentrated at their disposal. The substantial deposits of fossil fuels are key resources to supply primary energy in Kazakhstan, Turkmenistan, and Uzbekistan. Figure 2 represents the total primary energy supply by various sources in the five countries over the last 25 years [34].

It can be observed from Figure 2 that fossil fuel-based energy supply is a common practice for these countries for the last 25 years. In contrast, Tajikistan and Kyrgyzstan are underprivileged in terms of fossil fuel reservations but fulfil their energy supply mainly from concentrated hydropower. It can be observed from Figure 2 that besides hydropower, other renewable energy (RE) sources are not utilised for energy generation.

Despite its access to diverse energy resources (fossil and non-fossil), Central Asia is facing a complex energy security crisis [10]. The provision of modern, affordable, and reliable energy services remains a challenge, especially in rural Central Asian regions. Rural communities in these regions cannot meet their basic energy needs due to the poor infrastructure of the energy supply systems and geographical isolation from the major energy production centres.

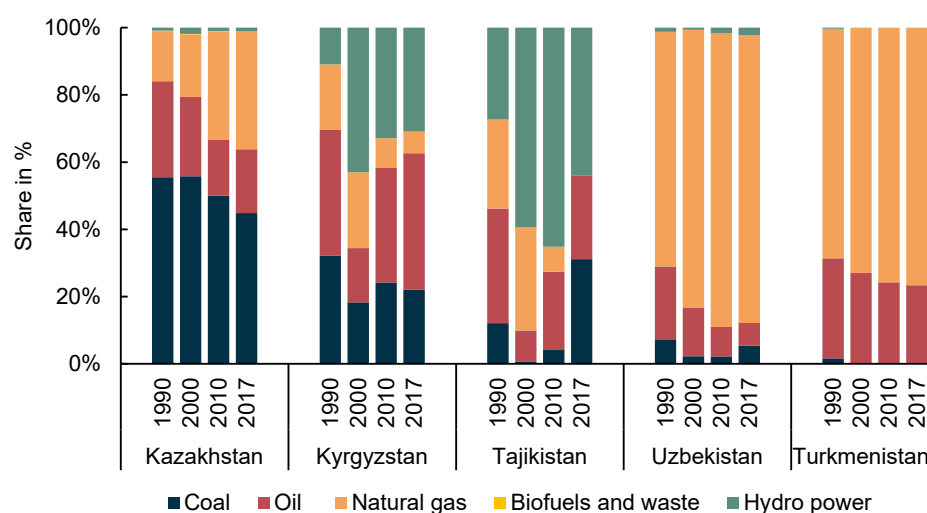


Figure 2. Total Primary Energy Supply in Central Asia by various sources (reproduced from [34], IEA (2019)).

The absence of suitable energy services leads people to use available natural resources to meet their basic energy needs. This heavy reliance on natural resources means considerable exposure to indoor and outdoor air pollution. Mountain societies in Central Asia are highly vulnerable to the impacts of climate change [35–38]. For example, Reyer [39] investigated the ways that Central Asia experiences climate change by presenting various sectors such as energy, water, food, and heat, and suggested that all of these factors will be severely affected by climate change.

1.3. Objective and Methodology

After independence in 1991, Turkmenistan and Uzbekistan have been on the track towards a speedy recovery in terms of infrastructural development and access to energy services because of their huge deployment of fossil-fuel resources. The export of the fossil-fuels to neighbouring countries (e.g., exports of natural gas to China and coal to Kyrgyzstan and Tajikistan) yields financial growth and stability to the mentioned Central Asian countries [16,33,40]. They then invest these capital inflows in their housing sectors as well as infrastructure development, especially in urban areas. Also, there are very limited information available related to the energy situation in Turkmenistan and Uzbekistan. Hence, this research article focuses on the remaining three countries (Kazakhstan, Kyrgyzstan, and Tajikistan) of Central Asia and investigates their rural energy supplies.

The available scientific information mostly focused on the effects of climate change, the water-energy nexus, and environmental issues in the context of Central Asia [41–45]. However, there is a gap in the literature regarding the distribution of energy services among urban and rural areas in Central Asia. Hence, the research described in this paper aims to perform a comparative analysis and assessment of the current status-quo of energy situation and challenges for selected case study countries of Kazakhstan, Kyrgyzstan, and Tajikistan.

This paper illustrates the current energy supply and consumption trends for various energy sectors of selected countries such as the power sector, heating sector, domestic hot water, and cooking in the rural areas compared to urban areas. Subsequently, the article highlights the potential of renewable energies in Central Asia. In order to perform the study, a qualitative comparative analysis was conducted based on a literature review, followed by the collection of data and statistical information. In summary, the collected information was utilised to display a comprehensive analysis of energy situation in rural Central Asia. Figure 3 displays the methodological approach of the presented article.

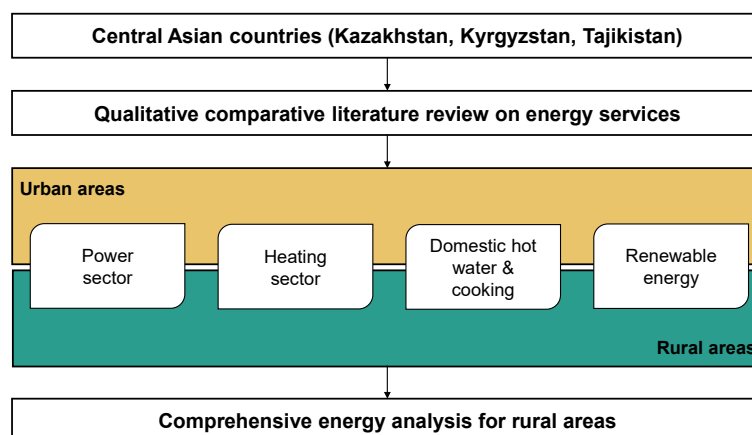


Figure 3. Graphical representation of the concept and structure of the presented review article.

2. The Central Asian Power Sector

The availability of plentiful energy resources has resulted in universal electricity access of up to ~100 % in urban and rural areas of Central Asia [46]. The power grid of Central Asia was set up by the Soviets in 1980. However, the infrastructure of the Central Asian power sector is now outdated and is not capable of fulfilling the growing electricity demand of the individual countries [47]. During the 1980s, the power transmission network of the Central Asian countries was interconnected to form the Unified Energy System of Central Asia (UESCA). The UESCA interlinked approximately 83 power plants (30% hydropower plants and 70% thermal power plants with a total capacity of 25 GW) located across the Central Asian countries with 220 kV and 500 kV transmission lines. This interconnection allows power to flow across the republics [48,49]. However, after independence from the Soviet Union in 1991, the interests of independent Central Asian countries diverged, especially within the energy sector. Turkmenistan and Uzbekistan withdrew themselves from the Unified Energy System in 2003 and 2009, respectively. As a result, Tajikistan was left alone from the unified transmission ring of the Central Asian countries [47,49,50]. Figure 4 represents the integrated Central Asian power network [48].

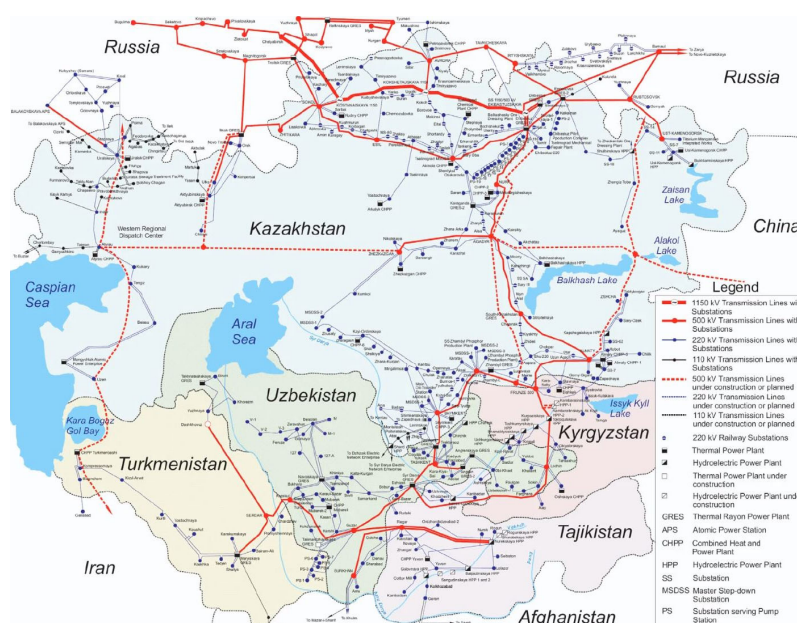


Figure 4. Central Asian power structure [48].

Due to the pre-existing electricity distribution system, the regions remain physically interconnected but each country now has its own power generation transmission and distribution strategies. Electricity generation capacity is distributed unevenly in Central Asia. For example, mountainous countries such as Kyrgyzstan and Tajikistan use their water resources to produce hydroelectricity, whereas Kazakhstan produces more than 80% of its electricity with coal-fired power plants, as the country has large coal resources [51]. Figure 5 represents the distribution of energy resources for electricity generation in Central Asian countries. Despite the widespread access to electricity in the Central Asian regions, the power sectors of individual countries suffer from many problems, the most common of which is the seasonality of supply and demand.

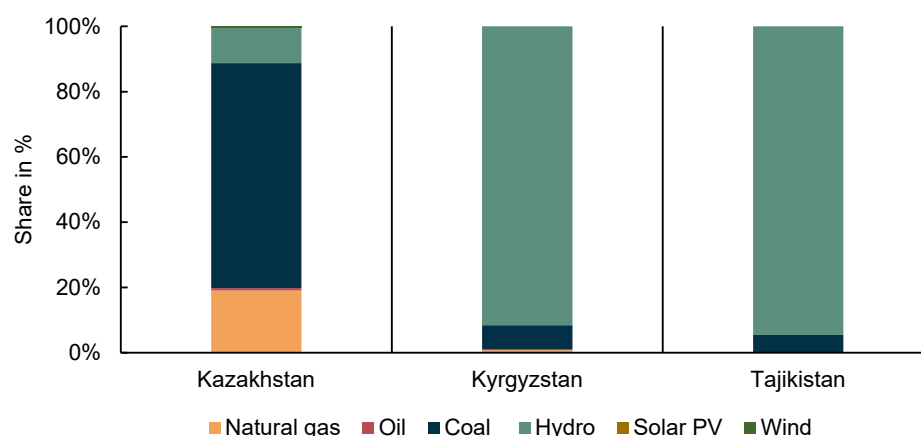


Figure 5. Distribution of energy sources in electricity production (reproduced from [51], IEA (2019)).

The power sectors of Kyrgyzstan and Tajikistan rely mainly on hydro resources, and the power demand of these countries is higher in the winter than in the summer. Due to the cold winters, the river flows decrease, which leads to reduced power production and power shortages. In the summer, the opposite is the case. The regions have therefore established an energy exchange in order to meet seasonal demand. Uzbekistan and Turkmenistan export natural gas to Kazakhstan, Kyrgyzstan, and Tajikistan, while Uzbekistan and Turkmenistan (downstream countries) have minimal water resources and therefore require water to flow from upstream countries (Tajikistan and Kyrgyzstan) for irrigation purposes during the summer and spring.

Kazakhstan, Uzbekistan, and Turkmenistan are directly dependent on their neighbours for water. Because of the winter power shortages, Kyrgyzstan and Tajikistan collect and store water for winter when they experience high power demand. As a consequence, the downstream countries do not receive enough water for agriculture. Because of the unequal and scattered distribution of the energy and water resources in Central Asia, significant tensions can arise between the fossil fuel-rich countries of Kazakhstan, Turkmenistan, and Uzbekistan; and the fossil fuel-poor countries of Tajikistan and Kyrgyzstan [47].

2.1. Kazakh Power Sector

Kazakhstan has 4% of the world's estimated coal reserves (~37 billion tons) and for this reason, more than 80% of its total electricity is generated in coal operated thermal power plants situated near coal mines [52]. Electricity in Kazakhstan is produced by 128 non-fossil fuels (coal-fired) operated power plants. The total installed capacity of power plants in Kazakhstan is 216.7 GW (some of them are already out of commission) and the available capacity is 187.9 GW [47].

Most of Kazakhstan's power generation facilities are old and obsolete, as they were typically constructed during the past Soviet era and use low-quality fuel [53,54]. However, Kazakhstan is considered to be one of the net electricity exporters in the Central Asian region and exports mainly to Russia, Uzbekistan, and Kyrgyzstan [54]. On the other hand, the power sector is incapable of maintaining an energy supply and stable frequency during peak loads, so the country needs to import electricity to bridge the gap between demand and supply as well as to regulate frequency [55]. Furthermore, over 40,000 kilometres of the Kazakh transmission and distribution network suffer from high transmission losses. The two main transmission networks are situated in the north (connected to Russia), and the one located in the south is connected to the Unified Energy System of Central Asia [55]. According to the Kazakh Minister of Energy and Natural Resources, "an average of 10% of its generated electricity is lost before it reaches the consumers due to the widespread deterioration of the power infrastructure" [52]. By comparison, the Kyrgyz and Tajik power sectors, which depend on each country's water resources, resemble each other in terms of energy crises.

2.2. Kyrgyz Power Sector

The Tien Shan mountain range covers almost 85% of Kyrgyz territory, which results in a large number of glaciers and permanent snow. This results in plentiful water resources that have been estimated to add up to 700 km³ [56]. The Naryn river is one of the primary water sources of the country, which originates in the Tian Shan mountains and flows across Kyrgyzstan and Uzbekistan. The enormous hydro resource is responsible for producing around 90% of total power with different small hydropower plants in Kyrgyzstan [51,57]. Electricity generation in Kyrgyzstan is heavily dominated by hydroelectric power and the rest of the electricity is produced by thermal generators. Most of the hydro powerplants (situated in Naryn cascade) are operated using water released from the Toktogul reservoir, located on the Naryn River in the Jalal-Abad province [58].

The transmission and distribution of electricity in Kyrgyzstan is governed by the National Electric System of Kyrgyzstan (NESK), which is transmitting and distributing control organization for power in Kyrgyzstan [57]. The electrification rate in Kyrgyzstan is around 99.8%, which covers the majority of rural and urban households. Because of the heavy subsidy, the price of grid-supplied electricity in Kyrgyzstan is approximately 0.01 USD/kWh, which is the lowest electricity price in the Central Asian regions [57,58].

In Kyrgyzstan, the energy demand is higher during winter as compared to summer. Hence, there is a significant difference available between interseasonal consumption, which was 2450 GWh in 2012. Furthermore, the winter demand consumption for residential consumers increased by 78% from 2009 to 2012, mainly because of growing urban areas (migration) and the need for electric-heating in urban areas. To fulfil the energy gap, Kyrgyzstan imports electricity during winter from neighbouring countries (i.e., Tajikistan, Kazakhstan) [58,59]. Figure 6 represents the comparative assessment of residential consumption in winter and summer.

The old transmission network results in higher transmission losses (around 30% of total output annually) [60]. Further to this, the Kyrgyz power sector experiences major concerns involving its supply quality due to its outdated infrastructure. Kyrgyz electricity users face an irregular supply of electricity as well as fluctuations in voltage because of reduced power production in the winter season [61,62]. Low-income rural mountainous households apparently experience interruptions in electricity services on a weekly basis [61]. According to the results of a survey of energy delivering services quality in 2015 by the World Bank, around 12% of Kyrgyz households had uninterrupted power supply, while almost 65% of households had power cut frequently during the year and 0.5% had daily power cuts. Additionally, around 50% of respondents reported problems with voltage (including low voltage and high voltage fluctuations) [61–63]. In summary, only modest improvement was implemented to improve the Kyrgyz power sector's overall performance over the last two and half decades.

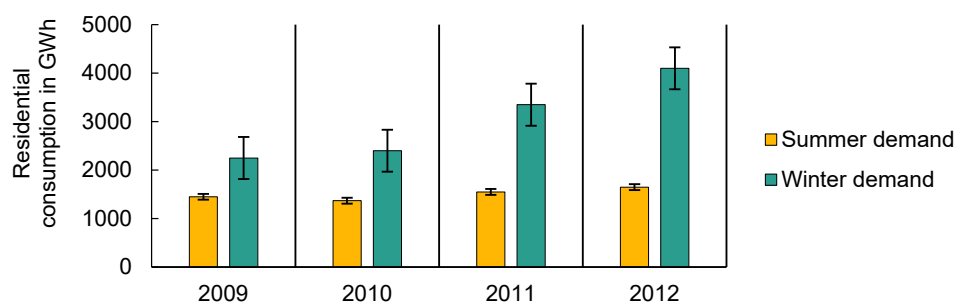


Figure 6. Residential consumption during winter and summertime in Kyrgyzstan (reproduced from [58], Wold Bank (2017)).

2.3. Tajik Power Sector

Geographically, Tajikistan is located upstream of the Amu Darya and Syr Darya river basin and therefore is endowed with abundant hydroelectric potential. Therefore, Tajikistan was placed among the list of the world's top 10 countries with the highest hydropower potential. The water resources at the country's disposal are a driving factor and are responsible for more than 90% of total electricity generation within the power sector framework [64].

Nonetheless, the state of the Tajik power sector is crucial and is facing crises. Nearly all the Tajik houses are connected to the national grid but around 70% of the population suffers from extensive electricity shortage issues during winter [65]. The freezing winter of Tajikistan is responsible for the reduced natural flow of water, making power production sensitive to available water flow, similar to in Kyrgyzstan. The low production of hydroelectricity and corresponding high electricity demand in winter (for heating) brings disturbances to the demand and supply cycle numerous times during winter. Figure 7 represents electricity consumption by the wealth group and its location. It can be observed that during the heating season, the households in Dushanbe consume electricity significantly (800–900 kWh/month) as compared to low-income rural households (200–300 kWh/month). The urban households frequently use electricity because they can afford it. Meanwhile, because of low-incomes and low power quality, electric heating is less common in rural Tajikistan.

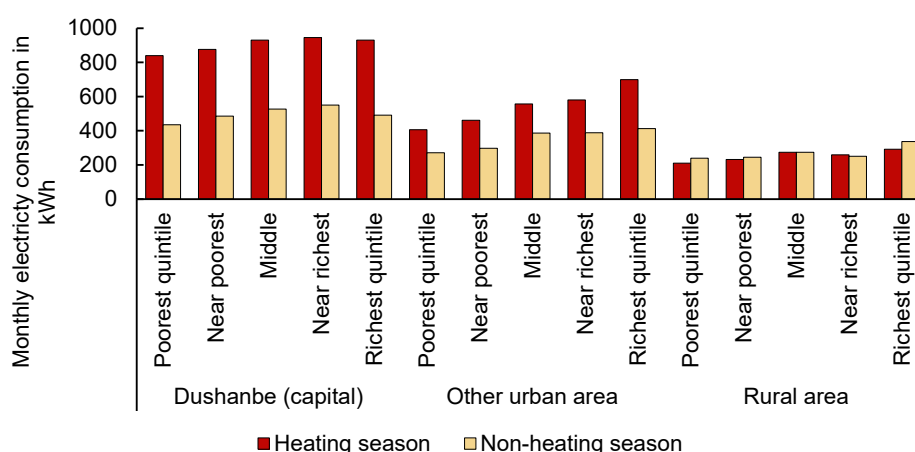


Figure 7. Electricity consumption by wealth group by location and during the heating season and non-heating season (reproduced from [66], World Bank (2014)).

Figure 8 represents the electricity import and export trend as well as electric power transmission and distribution losses of total power output in Kazakhstan, Kyrgyzstan, and Tajikistan over the years.

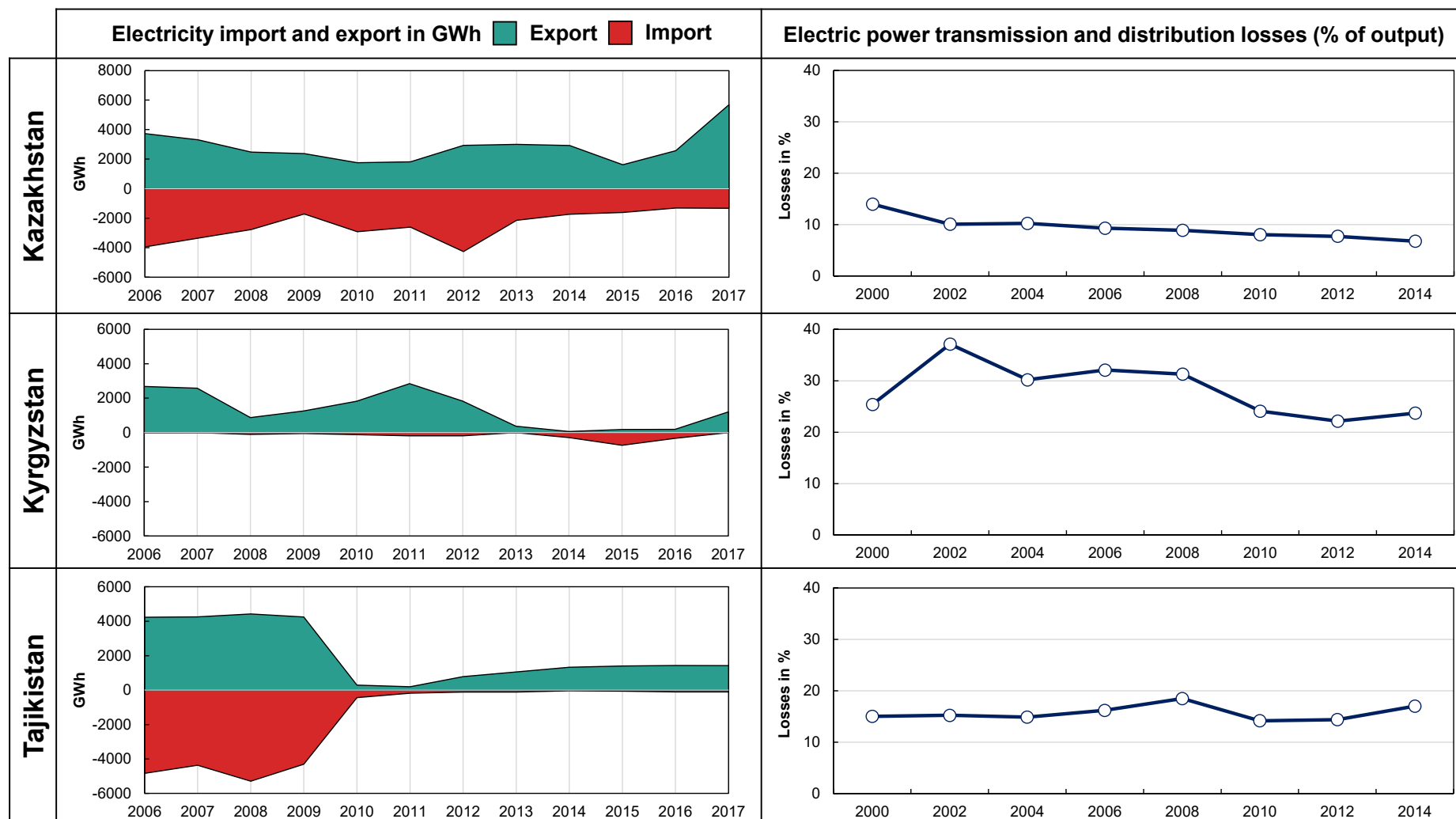


Figure 8. Data on electricity import and export in GWh and electric power transmission and distribution losses in % of total output [60,67].

The high electricity consumption during winter by (urban) Tajik people increases the burden on the power sector. It was estimated that climatic conditions in the winter reduced the generation capacity by around 1250 MW from the various hydropower plants. The reduced generation has resulted in a considerable amount of supply deficit. It has been projected that the winter electricity shortages are at least 2000 GWh, nearly 20% of the total winter electricity demand [68].

The issue of electricity shortage became serious during 2009 when Tajikistan was left separated from the Unified Energy System of Central Asia, and therefore, the inter-border energy trade stopped (c. f. Figure 8). Moreover, the age of the power transmission network aggravates a significant amount of losses (~30%; c.f. Figure 8) and contributes to making the winter energy crises more critical [65,66].

An interrupted and unreliable electricity supply has a significant negative influence on business development in Tajikistan. According to the World Bank survey on Business Economic Environment in 2008, 80% of firms reported that power supply reliability is a key barrier for doing business in Tajikistan [69]. However, the Tajik government has identified the importance of energy security and the impact of energy security on its development. Hence, several measures were introduced which can help to fill the gap of the demand such as energy loss reduction, energy efficiency buildings, and large hydropower plants to generate more electricity [69].

3. The Central Asian Heating Sector

Especially in the high-altitude and cold mountain Central Asian regions, more than half of the annual precipitation falls as snow during the winter (generally from November to March) [70]. The heating period is semi-annual in most of the Northern and Central Asian regions, resulting in around 6000 heating degree days [71]. Figure 9 represents the monthly air temperature of selected cities of the case study countries.

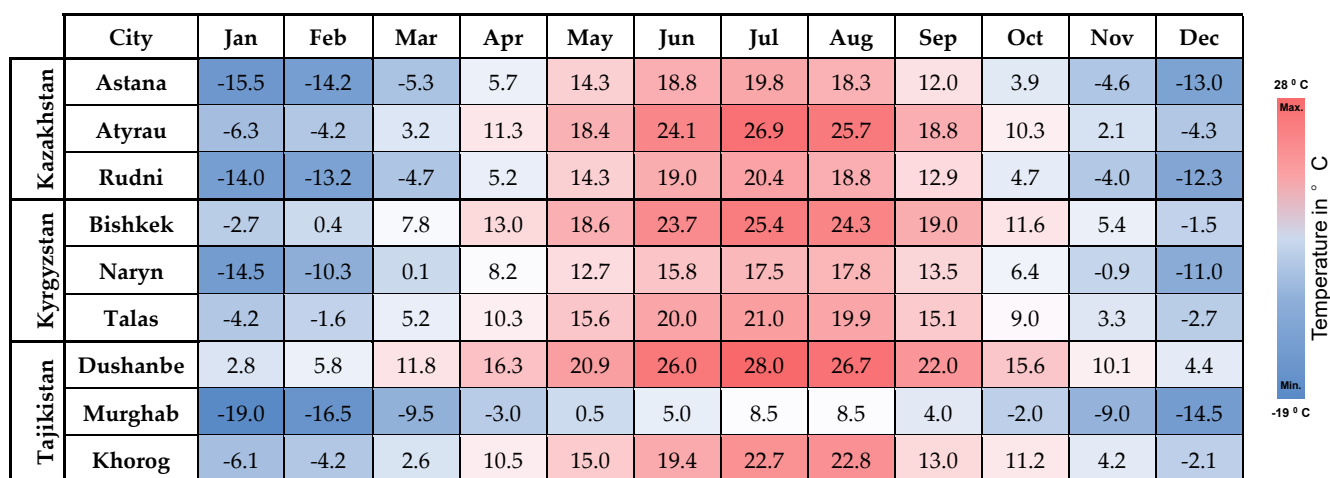


Figure 9. Monthly air temperature heat map of various cities (reproduced from [72], Meteonorm (2018)).

Snow precipitation during winter as well as the cold climatic characteristics of Central Asia with long winters define heating as the primary need of the local people. Therefore, residential energy has a sizable portion in the overall energy consumption framework in Central Asia. It can be observed from Figure 10 that in Kyrgyzstan, residential buildings have the highest share of energy consumption and for Tajikistan and Kazakhstan, residential buildings are the largest energy consumers, followed by the industry sector [73].

It is estimated that almost 60% to 80% of buildings in Central Asia are earthen buildings built mainly from soil, clay, and adobe without proper building codes [74]. The age of dwellings in combination with vernacular architecture is a key reason for the high energy utilisation in the residential sector for heating in Central Asia. The absence of modern heat energy

supply services, low-income, and high heat demand of low energy-efficient building stocks in rural localities promote solid fuel consumption for house heating [71,75]. House heating with solid fuels is common practice in rural Central Asian regions. Generally, rural households used to fuel coal, wood, wood branches, and self-made cow dung in low-efficient traditional heating stoves with a typical thermal efficiency below 40% [76].

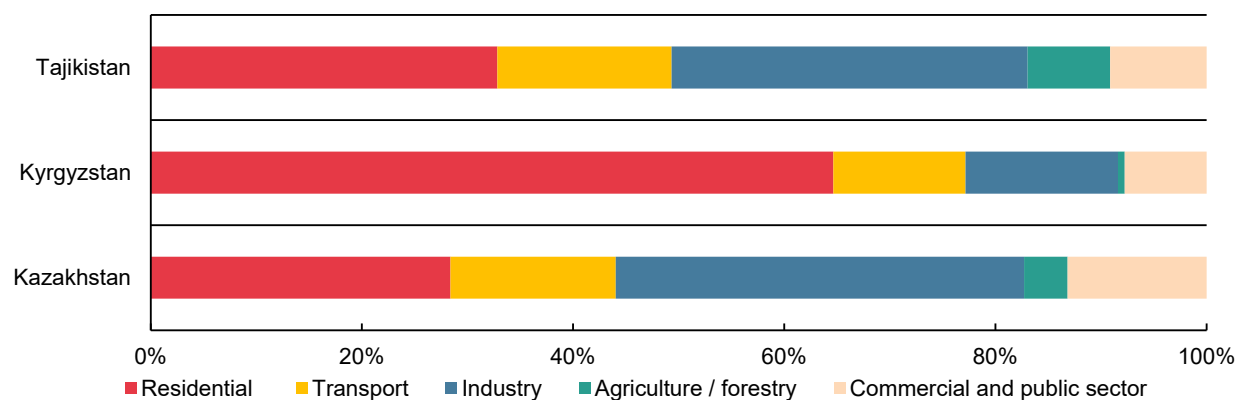


Figure 10. Central Asian total final energy consumption by sectors in 2018 (reproduced from [73], IEA (2020)).

3.1. Kazakh Heating Sector

The heating period in Kazakhstan varies from 140 to 230 days (4–8 months) according to the location of the region. The average air temperature in winters ranges from -16°C to -2°C from north to south [77]. The range of sub-zero air temperature underlines that space heating is a basic need for the Kazakh people. The abstracted conventional resources are responsible for the energy-driven economy, and therefore, Kazakhstan is the wealthiest country among the Central Asian regions. Hence, three-fourth of its urban areas have access to the district heating network (DH) (which mostly operates with coal and/or natural gas) and are connected with a natural gas supply. Typically, the households that are not connected to the DH grid (rural homes) rely on coal-based space heating solutions [71,77]. Figure 11 represents the comparison of the heat energy supply distribution of urban and rural areas.

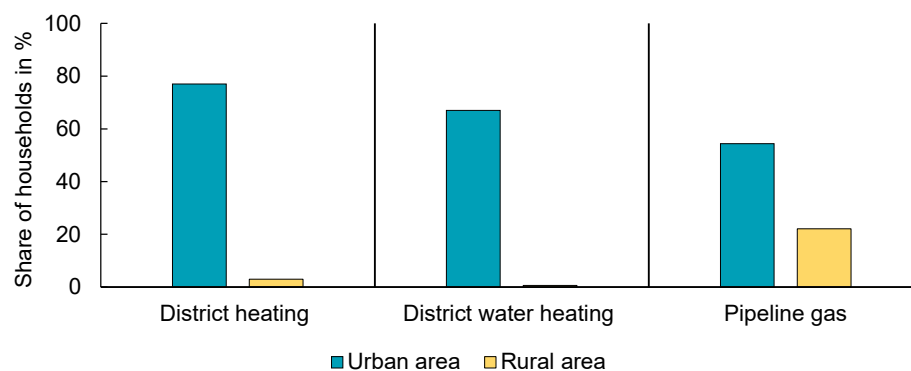


Figure 11. Household access to heat energy services in Kazakhstan during 2014 (reproduced from [71], IAEE (2017)).

Even though with its rich natural energy resources, the semi-urban and rural areas of Kazakhstan are not connected with central heat distribution centres. Therefore, more than 70% of rural Kazakh dwellings intensively use coal as a primary source for space heating purposes [75]. Howie and Atakhanova [75] estimated that coal consumption for

residential heating dramatically increased by almost 45% between 2002 and 2012. It was observed that consumption increased from 3.9–5.8 tons to 5.6–8.4 tons based on the region because of more support towards the coal-based traditional heating approach [75]. It was identified that coal is a key factor that contributes to indoor and outdoor air pollution. This leads to frequent health diseases such as lung cancer, respiratory disorders, and other diseases [78].

3.2. Kyrgyz Heating Sector

Kyrgyzstan—one of the low-income countries in Central Asia—has a complex framework for heat energy supply systems, and according to local people, it is not sufficient for heating their homes. Because of limited incomes, accessing energy for primary needs is a costly task for many rural people, especially in mountainous areas [79]. The Kyrgyz weather is characterised and influenced by the mountain ranges covering almost 90% of the country's territory. The cold climate is responsible for the long heating period of about 6 to 9 months in Kyrgyzstan. To fulfil the domestic space heating requirement, a few houses (17% of the country's households) mainly in the capital and its nearby areas are connected to the DH network.

The existing DH networks were commissioned around 30 to 50 years ago and hence they run under deteriorating operational conditions, resulting in significant heat losses (around 25–30%) [63]. As a result, electric radiators are a preferably used by the urban population as a backup heating system. Hence, despite having a DH connection, urban people frequently use an electricity-based domestic heating system during the heating period in Kyrgyzstan. The metropolitan areas that are not connected to the DH network (around 35% of households) directly depend on electricity for heating. The increased reliance on electricity for heating in urban areas during peak hours results in high residential electricity consumption during winter (c.f. Figure 6) [59,63]. The existing electricity generation capacity directly depends on available water flows, and the distribution network is already strained. The increased reliance on electricity for heating by urban Kyrgyzstan results in recurrent power shortages. Therefore, in a general manner, despite the low electricity tariffs, it is not a reliable option to consider electricity as the primary source of heating in Kyrgyzstan. Further to this, rural settlements/high-altitude rural communities in Kyrgyzstan are typically situated far away from the major energy production centres, and therefore it is not easy to connect remote Kyrgyzstan with the heat energy supply network. Hence, in attempting to meet their space heating needs, rural Kyrgyz people heavily rely on solid fuels operated/fired low-efficient traditional heating stoves or boilers. According to the World Bank, around 73% of rural homes intensively use non-sustainable biomass / coal to maintain thermal comfort (c.f. Figure 12). Limited income sources and fluctuated electricity service are the prime reasons for rural families to switch to solid fuels to meet their primary needs [63].

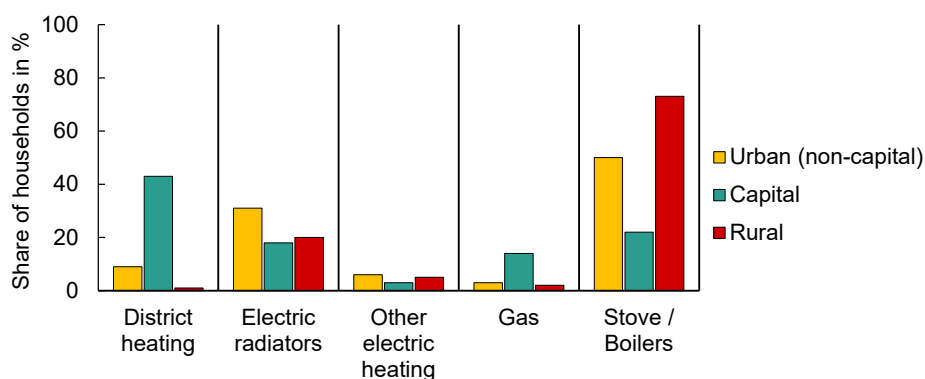


Figure 12. Households' main sources of heating by settlement type (2015) (reproduced from [63], World Bank (2015)).

Rural households in Kyrgyzstan use a variety of solid fuels to meet the residential heat demand. For house heating, most rural families prefer to use coal or wood and, less frequently, animal dung [61]. It is projected that during the heating season, typically, an average rural family would need to purchase 2 to 5 tons of coal in combination with 0.5 to 7 cubic meters of firewood and also 5 freight loads of dried cow dung to maintain thermal comfort in the house. Over-usage of non-sustainable firewood is one of the prime reasons for deforestation in Kyrgyzstan [80]. Furthermore, the burning of non-sustainable solid fuels contributes to indoor and outdoor air pollution [81]. In addition, the high reliance on firewood mainly leads to a negative impact on riparian forests of Kyrgyzstan [82]. The typical domestic heating system (traditional heating stove) and solid fuel storage for individual houses are illustrated in Figure 13.

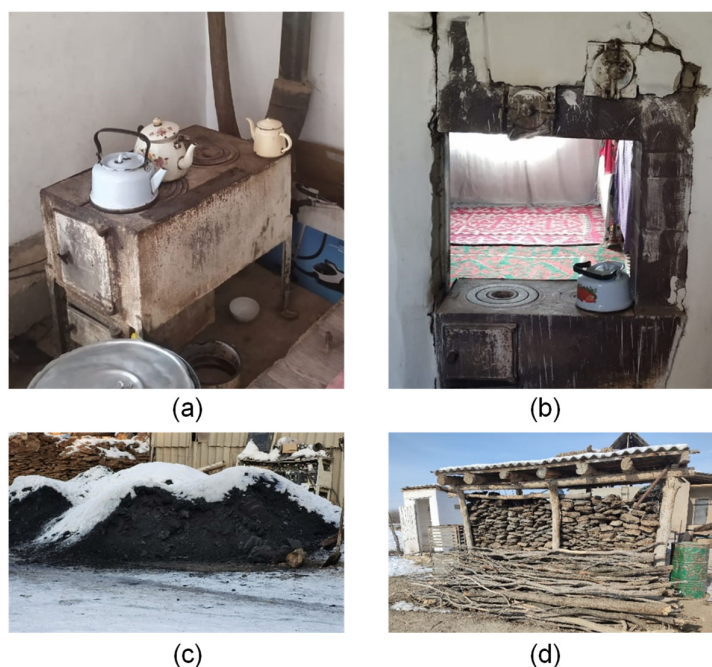


Figure 13. Traditional heating method in Kyrgyzstan—(a): Traditional heating stove placed at the corner of the room; (b) heating stove that is positioned in the wall between two rooms to heat-up two rooms simultaneously; (c,d) solid fuel storage of an individual household (Source: Authors).

3.3. Tajik Heating Sector

Like the Kyrgyz heating sector, the Tajik heating sector faces critical issues with its heat supply. As a result of the outdated DH network as well as the unreliable energy supply, a significant portion of the Tajik population cannot fulfil their residential heat demand. Only 8% of Tajik houses are connected to the DH network that is characterised by an unreliable service quality. Because of the price increases for natural gas and the inconsistent natural gas supply, most district heating plants in Tajikistan are out of operation. Therefore, like Kyrgyz people, people in urban Tajikistan directly rely on electricity-assisted heating systems. As a consequence, these circumstances aggravate the high electricity demand and increase the burden on transmission networks. This results in extensive shortages of electricity during the winter [69,83].

As a result of substantial unmet energy demand, rural people heavily depend on solid fuels and operate traditional stoves that work inefficiently and are responsible for high ambient air pollution. However, house heating methods differ by energy source, type of dwelling, location, and residents' financial status [66]. Figure 14 categorises primary heating source by building type and location, and it can be observed that around 80% of

multi-apartment buildings in urban areas use electricity as a primary heating source. Generally, high-income families are located in urban areas and, therefore, electric heating is affordable for them. However, middle-income families in urban areas and low-income families in rural areas have a high reliance on wood and coal for domestic space heating in Tajikistan [83].

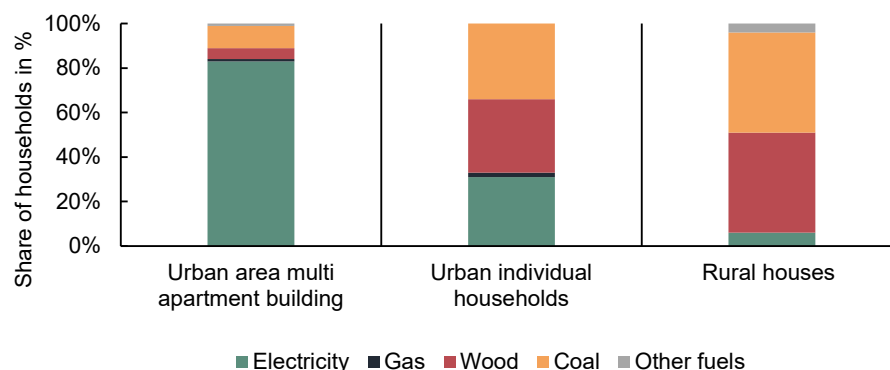


Figure 14. Primary heating source by building type and location in 2015 (reproduced from [66], World Bank (2014)).

The sizeable rural population of Tajikistan would rather not switch to using electricity or any modern heating supply because of the cheap/freely available nature of biomass (i.e., wood and cow-dung); on the contrary, they find electricity is expensive [84]. It can be outlined that the electricity tariff in Tajikistan is 2.32 US cents/kWh, which is the second-lowest electricity tariff in Central Asia after Kyrgyzstan. The opinions of local people can help to understand the low-income scenarios in rural areas and their support for traditional heating approaches.

Figure 15 characterises a comparative analysis of GDP per capita and death rates from indoor air pollution (the number of deaths per 100,000 individuals). It can be seen that Tajikistan has the highest death rates from indoor air pollution, followed by Kyrgyzstan among the Central Asian regions.

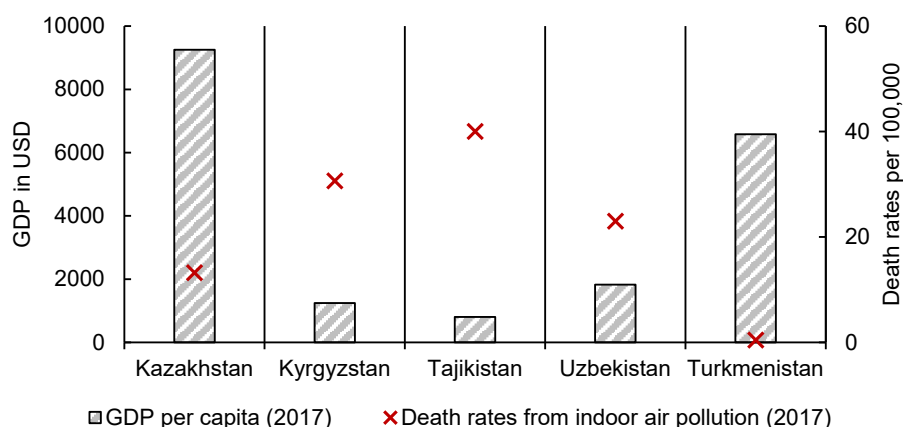



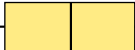




Figure 15. Comparative analysis of GDP per capita (2017) vs. death rates from air pollution (2017) (reproduced from [85,86], World Bank (2017), OWID (2017)).

Table 2 represents the relative description of the energy demand indicator as well as the current energy supply indicator for residential space heating in rural areas of Kazakhstan, Kyrgyzstan, and Tajikistan.

Table 2. Relative analysis of energy demand and supply indicators for the rural residential space heating sector (data according to [59,62,63,65,71,83,87,88]).

Country		Kazakhstan	Kyrgyzstan	Tajikistan
Energy demand indicators	Typical rural residential house			
	Heating degree days	Over 5000	2200 to 4900	2000 to 7000
	Range of average heat demand (kWh/m ² /year)	200  270	240  360	250  350
Energy supply indicators	Electricity for heating	<ul style="list-style-type: none"> Frequent power shortages, as well as massive coal reservoirs, lead people towards traditional heating. 	<ul style="list-style-type: none"> Because of inadequate power supply and low-income, electric heating is not increasing in rural Kyrgyzstan. 	<ul style="list-style-type: none"> Low-incomes and an inconstant electricity supply make it unaffordable and unreliable for heating, respectively.
	District heating	<ul style="list-style-type: none"> DH networks operated by coal and natural gas are very common in urban areas. However, rural areas are not connected. 	<ul style="list-style-type: none"> Only 19% of total Kyrgyz households are connected to very inefficient DH systems which are concentrated in urban areas. 	<ul style="list-style-type: none"> Only 8% of Tajik households are connected to DH in urban settlements. Major DH systems are not in operation.
	Traditional methods	<ul style="list-style-type: none"> Coal-operated/fired boiler use for space heating purposes by 70% of the rural population. 	<ul style="list-style-type: none"> Traditional heating methods involving solid fuels commonly used by rural households (around 73%). 	<ul style="list-style-type: none"> Traditional heating stoves are the favoured heat supply systems for more than 80% of households.
	Heating fuels in heating season	<ul style="list-style-type: none"> Coal (5–8 tons), natural gas and electricity (according to financial capacities) 	<ul style="list-style-type: none"> Coal (2–4 tons), firewood (1–4 m³) and cow-dung (1–2 truckload) 	<ul style="list-style-type: none"> Coal (1–3 tons), firewood (1–3 tons) and cow-dung (1–2 tons)

4. Hot Water Preparation and Cooking in Central Asia

4.1. Domestic Hot Water

Rural areas in Central Asia are less likely to connect with the centralised water supply system and therefore a limited portion of the rural population has access to piped water in the house for drinking water and for other purposes (i.e., domestic hot water preparation, washing, cleaning, etc.). Freshwater resources in Central Asia are mainly classified as surface water bodies and groundwater. The high proportion of usable water comes from high-land rivers (Kyrgyzstan and Tajikistan), which are transboundary rivers [89,90]. Table 3 represents the proportion of population with access to drinking water for the urban and rural population in Kazakhstan, Kyrgyzstan, and Tajikistan.

Table 3. Access to drinking water for population (%) (reproduced from [89], MDPI (2016)).

Area	Kazakhstan	Kyrgyzstan	Tajikistan
Urban area	78	85	93
Rural area	>35	58	49

It can be concluded from Table 3 that generally, urban areas are supplied with drinking/usable water. In contrast, because of their distant location, rural areas are not strongly connected and have limited access to the central water supplies. Instead, the rural population fetches drinking water from irrigation canals, ditches, and rivers [90]. The low access to the availability of piped water results in limited consumption of hot water. Low-income rural households generally use traditional heating stoves to prepare hot water with a cooking pot (this can be seen in Figure 13) and/or use an electric kettle. Further to this, due to the absence of piped water connections as well as limited income opportunities, typically, rural homes do not have an in-built shower room to take a shower. Rural people use a central/community bathhouse (Banya) to take a shower. Therefore, water consumption in rural areas is limited. The same situation applies with hot water for cooking, washing dishes washing and clothes.

As a result of this very limited hot water use, there is no authentic data source found by the authors which helps to characterise the domestic hot water consumption in urban and rural areas. The households do have precise data on hot water consumption because they fetch the water from outside. Therefore, no water meter is available to measure hot water usage.

4.2. Cooking Methods and Fuel Sources for Cooking

The energy sources and access to modern fuels for cooking differ from region to region in Central Asia. In Kazakhstan, because of the widespread availability of Liquefied Petroleum Gas (LPG) and electricity, urban populations use them for cooking purpose [91]. However, rural households in Kazakhstan have lower access to gas networks, hence these areas mainly rely on solid fuels (coal and wood) and/or electricity for cooking. Typically, rural people use a combination of fuels for cooking in the same way as for space heating according to their financial capabilities and the season [77].

In Kyrgyzstan, LPG is favourable energy source for cooking in urban areas (45% of total households) and electricity for rural areas (60% of total households). However, the sizable population in the rural provinces (34%) burns solid fuels for cooking (most commonly wood, followed by cow-dung and agricultural waste) [61].

Due to frequent shortages as well as seasonal interruptions in electricity in Kyrgyzstan and Tajikistan, most rural households prefer to rely on locally available solid fuels. Therefore, according to the availability of electricity, Tajik people prefer electricity for cooking, followed by natural gas (42% and 17% of rural households, respectively). In addition to this, around 37% burn solid fuels for cooking in Tajikistan [92].

5. The Potential of Renewable Energy in Central Asia and Current Trend

Shadrina [93] identified the potential of non-hydropower forms of renewable energy (i.e., solar, wind, biogas etc.) in Central Asia, and revealed that despite their enormous potential, non-hydropower renewable energy is yet to be unleashed. Besides its ample fossil fuel resources, Central Asia has a high potential for RE, which can generate energy sustainably. The abstracted dense river networks in Tajikistan and Kyrgyzstan make them superior for hydro energy [94]. Apart from hydro resources, both countries are blessed with a high potential for solar energy because of their high-altitude characteristics [95]. The potential for solar energy is available in a wide spectrum in Kazakhstan, Uzbekistan, and Turkmenistan as well. Considerable wind energy potential is available in Kazakhstan and Turkmenistan, followed by solar energy [64,96–98].

Kyrgyzstan formulated an energy-related policy in 2008 to accelerate these alternative energy sources. However, there was no remarkable progress achieved to expand the Kyrgyz RE sector. Baybagyshov and Degembaeva [99] mentioned that the low solvency as well as limited incentives from the government for RE technologies are the key reasons for the limited expansion of RE in Kyrgyzstan to date. Similarly, Tajikistan also adopted several program documents to expand the RE sector. However, there are inconsistencies for meeting the target in Tajikistan. To meet their growing demand, Kyrgyzstan and Tajikistan keep increasing the installed capacity of hydropower because of their abundant hydro resources. In contrast, other RE resources are mainly untapped. Uzbekistan also uses very limited hydro resources to produce electricity. In addition, its major solar energy potential is untapped and it has no industrial-scale solar power plants. Also, wind potential has not been studied scientifically and is considered as a gap in local research. To foster RE development, Uzbekistan is taking selective measures to establish proper energy legislation. RE development in Turkmenistan is negligible, as Turkmenistan is heavily reliant on natural gas power generation [100].

Figure 16 portrays the trend of the installed renewable energy capacity in Central Asia over the last 20 years. Because of the insignificant contribution of RE sources, Turkmenistan is excluded from the representation. It can be determined from Figure 16 that apart from hydro energy, the employment of other RE resources is mainly untapped. However, Kazakhstan has noticeable progress in RE development.

On the other hand, a growing body of literature provided evidence that the available RE sources have a phenomenal potential to generate energy to meet unmet demand in Central Asia. Table 4 characterises the literature matrix of selected research articles that focuses on individual countries and their RE potential. It is not practical to present the study of an individual country's RE profile. Therefore, the literature matrix can guide a list of key literature to understand the RE profile of individual republics (Kazakhstan, Kyrgyzstan and Tajikistan) as well as Central Asia as a whole (which covers Uzbekistan as well as Turkmenistan). The detailed investigation in Table 4 identifies that the unique characteristics of the Central Asian region offer a significant potential for renewable energies, which include hydro energy, solar energy, wind energy, biomass energy, and geothermal energy according to the geographical location of the region. However, the available RE sources are usually not exploited in favour of local rural communities. The current energy policies and legislative framework, especially in Kyrgyzstan and Tajikistan, are considered as key barriers to producing electricity with RE sources. The non-cost-effective electricity tariff is significantly below the estimated cost of energy generation from alternative sources. Therefore, investors are not motivated enough to invest in the RE sector. Furthermore, it has been commonly observed in Central Asia that potential investors struggle to obtain loan/finance from regional banks. As a result of this limited financial support, the high capital investment cannot be supported by the investors. Besides investment complexity, special and technical knowledge of RE is either missing or lacking in Central Asia, as there are limited technology providers and knowledge distributors in the local RE sector [64,96,101].

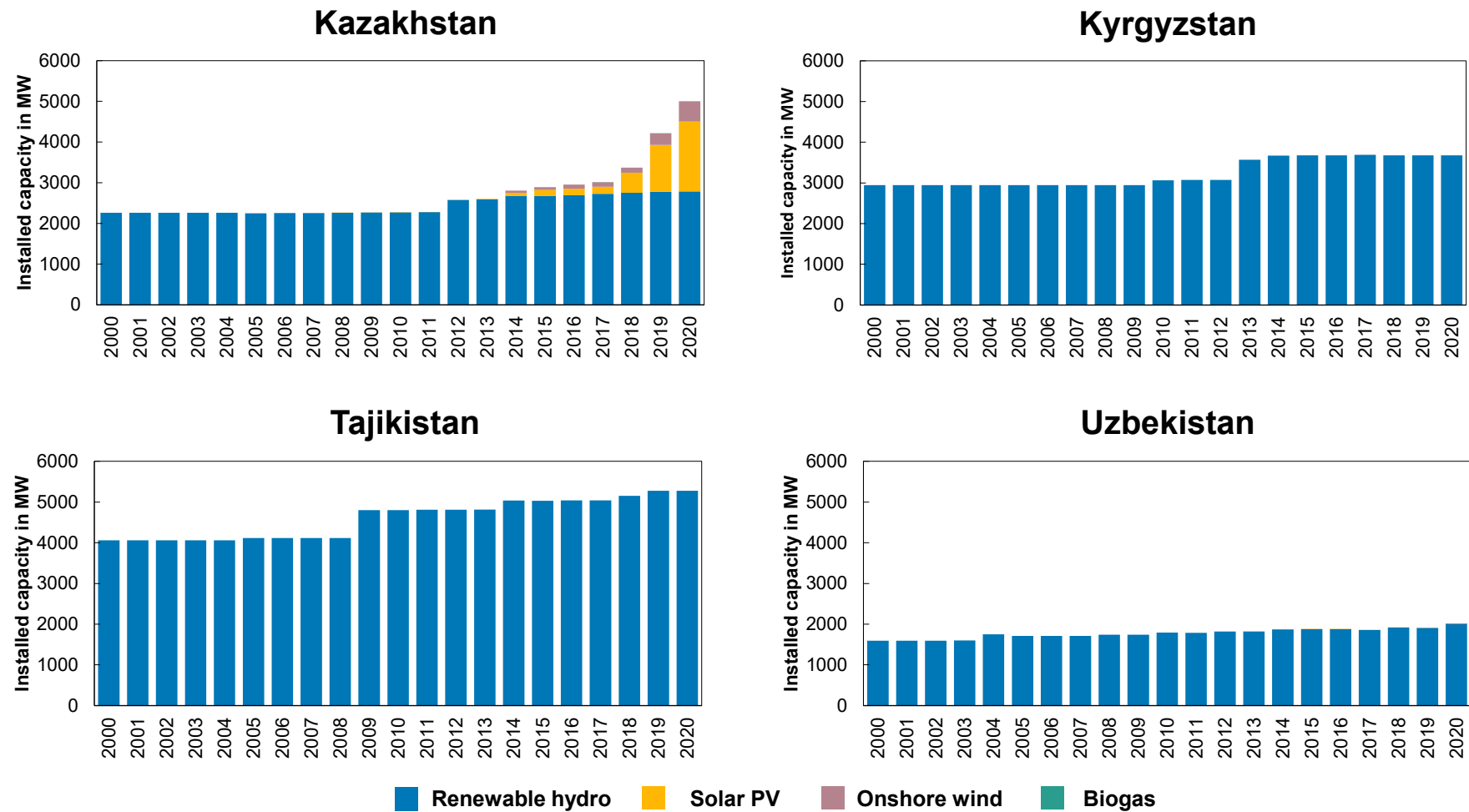


Figure 16. The trend of installed renewable energy capacity in Central Asian countries (reproduced from [102], IRENA (2020)).

Table 4. Literature matrix to assess the potential of renewable energy in Central Asia.

	Author	Research Title	Research Aim	Key Findings
Central Asia	Shardina (2020) [93]	Non-Hydropower Renewable Energy in Central Asia: Assessment of Deployment Status and Analysis of Underlying Factors	This paper aimed to assess the reasons behind the untapped and limited development of RE sectors in Central Asian countries.	The article summarises that RE sources are distributed unevenly, and the author also suggested policy implications to improve the commitment to RE in Central Asia.
	Nurdavletova and Akatayeva (2018) [96]	The renewable energy in the regional development of Central Asia	The main objective of the article was to investigate the available alternative sources in Central Asia and inter-regional complexity.	The article provided a glance at the potential of the RE sector in individual countries and key hurdles in detail for the implementation of RE in Central Asian republics.
	Abylkasymova (2019) [103]	Wind Power Potential of the Central Asian Countries	Theoretical wind power supply capacity as well as existing wind power installations were investigated as a key aim of the article.	Wind power has significant theoretical potential in all Central Asia countries. Over 70% of regional total wind potential is concentrated in Kazakhstan.
	Gubaidullina et al. (2017) [104]	Renewable energy and the regional prospect on sustainable development of Central Asia	The paper aimed to provide useful information on the issues of renewable energy in Central Asia, as well as the insight of RE status for individual countries.	The most rapid development in the field of renewable energy is noticed in Kazakhstan and the least developed sphere of RES is in Turkmenistan.
	Kiseleva et al. (2017) [105]	Efficiency estimation for the grid-tie photovoltaic stations construction in some regions of Central Asia and Transcaucasia	This techno-economic assessment evaluated the construction of network PV farm (5 MW) in selected regions of Central Asian countries.	By consideration of local feed-in tariffs, the simple payback period was determined to last 4–6 years in different regions of Central Asia for small scale PV farms (5 MW).
Kazakhstan	Zavadskiy and Revalde (2020) [106]	Problems of development of renewable energy facilities in rural regions on the example of Kazakhstan	This manuscript presents an outline of the difficulties and problems with the development of renewable energy sources in the rural regions of Kazakhstan	Kazakhstan possesses great renewable energy potential, especially in rural areas (solar, wind and bioenergy). The research article also recommends employing a special programme/policy to promote RE in Kazakhstan.
	Vakhguel't (2017) [107]	Renewable Energy Potential of Kazakhstan	The article presents the recent status quo of available potential of hydropower, wind power, solar power, geothermal energy, and bioenergy and their available operations in Kazakhstan.	Kazakhstan has a great potential for renewable energy production. Most of the Kazakh territory has great solar potential as well as considerable wind energy.
	Karatayev et al. (2016) [108]	Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy	With the help of the analytical hierarchy process, this paper investigates and ranks the different barriers towards the adoption of renewable energy in Kazakhstan. Also, it provides interesting insights into the country's legal framework.	It was identified that sustainable and affordable RE systems toned to be introduced in Kazakhstan for low carbon energy generation. Despite abundant available RE resources renewable energy currently contributes to less than 1% of the country's power generation.
Kyrgyz-	Abidov et al. (2020) [109]	Comparative Analysis of Some Types of Renewable Energy Sources	The article discussed the current state and possibilities of using alternative energy in Kyrgyzstan. It also assessed non-traditional renewable energy	The article identified that each type of RE source has its positive benefits in various regions of Kyrgyzstan. It also explained the reasons behind the insufficient use of RE in Kyrgyzstan.

			sources as well as the economic efficiency and its payback period.	
	Baybagyshov and Degembaeva (2019) [99]	Analysis of the usage of renewable energy in Kyrgyzstan	The manuscript defined the analysis results of the opportunity of using renewable energies (Solar, wind, hydro, biomass, and geothermal) in Kyrgyzstan.	The analysis showed that the country has a great potential for renewable energy, which is unexploited. The use of renewable energy for Kyrgyzstan should be considered as a solution to population's socio-economic problems in the decentralised high-altitude regions region.
Tajikistan	Schulz et al. (2014) [110]	The energy supply for mountain settlements in Tajikistan based on renewable energy sources	This article investigated the electrification of mountain settlements/communities of Tajikistan by means of combined forms of renewable energy sources (i.e., a small hybrid hydropower station, small PV station).	The article claimed that there is an immediate need to solve the seasonal deficiency of the Tajik power sector. It suggests that a small-scale hybrid power station operated by combined RE sources will be suitable for sustainable electricity supply for remote settlements in Tajikistan.
	Doukas et al. (2012) [111]	Promoting renewables in the energy sector of Tajikistan	The document presented multi-dimensional approach to identify the suitability of decentralised heat production in Tajikistan.	Technically, a low-pressure solar water heater is a more suitable design for Tajikistan. Also, the paper identified the hurdles for further development of decentralised heat production.

6. Analytical Discussion and Future Perspectives

The previous sections of the article provided the background and detailed information required to realise the complexity associated with the energy supply in rural Central Asia. The key idea of the presented article was to review and display the comprehensive energy situation of rural Central Asia. The key findings from the review article are listed below:

- According to the climatic situation of Central Asia, space heating is a necessary energy need for local people. Therefore, most of the energy is consumed for domestic heating as compared to cooking and lighting.
- Because of the Soviet Union's development in the late 1990s, all Central Asian countries are nearly electrified. However, the transmission lines and the power sector of Kazakhstan, Kyrgyzstan, and Tajikistan are obsolete and facing a similar issue of inter-seasonal demand. This can be immediately linked with the heating sectors of these countries. The provision of the DH network is mainly concentrated in the urban areas, and therefore, the urban households more often use electric heating systems. This increases the burden on the power sector and causes persistent shortages/outages. The low-population remote settlements lose power supply first. Hence, the actual electricity access is neither reliable nor affordable, especially for rural people. Hence, to meet primary energy needs, the rural population intensively use solid fuels.
- Rural settlements in Central Asia experience a high degree of energy scarcity and vulnerability. The majority of the rural population directly depends on the environment and fulfil their basic energy needs with the traditional approach/non-sustainable solid fuels.
- It can be identified from the presented review article that the energy infrastructure of Central Asia plays a critical role in terms of energy access.
- Central Asia is endowed with a great amount of RE resources. However, the renewable sector is not yet exploited because of the limited infrastructure, current energy policies, and a lack of scientific knowledge.
- To enhance the energy supply and services, the untapped RE resources in Central Asia are the most suitable resources for establishing sustainability in rural Central Asia.

Figure 17 provides a conceptual representation of a typical thematic solution which can be considered as future perspective. Also, it listed the key drivers (local boundary conditions) which influence the provision of energy services in rural Central Asia.

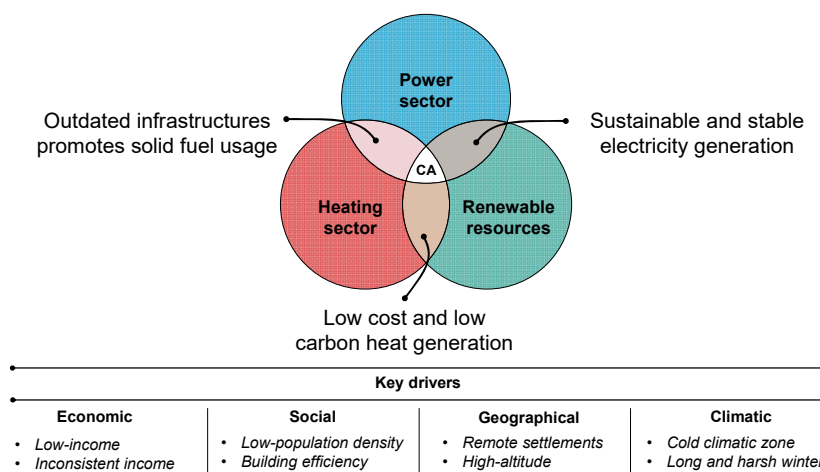


Figure 17. Thematic solution and key drivers which influence the provision of energy services in rural Central Asia (CA).

To reduce energy insecurity in rural areas, RE sources can be utilised to provide sustainable and stable electricity (i.e., solar photovoltaic farms). This solution can reduce the burden on the national grid, as additional stable power generation can be achieved with one of the RE sources. Similarly, RE sources can be potentially utilised to provide low cost and low-carbon domestic heating solutions (i.e., solar thermal collectors, solar air heaters, etc.). For example, Mehta et al. [112] identified that a solar-thermal heating system has a high potential for sustainable heat supply on the residential level, while the integration of solar-thermal operated system contributes to reducing the considerable amount of non-sustainable solid fuels of high-altitude rural Central Asian (Kyrgyz) houses.

However, to increase the viability of the proposed thematic solution, one needs to address the key drivers (local boundary conditions) mentioned in Figure 16, such as social, geographical, climatic, and economic dimensions while designing energy supply solutions. Future studies could examine a detailed assessment of energy supply systems based on RE to investigate the viability and impact of RE on the provision of energy services in rural Central Asia from a techno-economic point of view.

7. Conclusions

Central Asian countries face energy crises, especially for energy security and energy services provision to the rural citizen. Like other developing countries, Central Asia's urban regions are developed and have access to modern energy services to fulfil primary energy needs. Arguably, Central Asia's rural settlements are more critical in terms of the provision of energy services to meet basic energy needs.

The rural regions in Central Asia are mainly marginalised and geographically isolated from the main economic and central energy production centres. Because of the limited communication in the context of modern energy supply, rural people excessively depend on natural resources such as solid fuels, agricultural waste, and charcoal for their daily energy needs. Hence, the provision of energy services has a high degree of deviation between urban Central Asia and rural Central Asia. The very limited availability of energy information for Turkmenistan and Uzbekistan makes them challenging to examine and compare in the presented study. Hence, the comprehensive analysis was performed for the remaining Central Asian countries: Kazakhstan, Kyrgyzstan, and Tajikistan.

It can be determined from the presented review that there is a strong link between household income level and energy behaviour. Moreover, despite the enormous renewable energy resources, the transition in the renewable energy sector is not considerable, and all the renewable energy sources are mainly untapped. The analytical discussion identified that the utilisation of renewable energy can be a suitable solution to improve energy services in rural areas.

To recapitulate, outdated and inefficient energy infrastructure, fluctuating energy import-export trade, growing energy demand, interregional energy conflict because of scattered energy resources, limited opportunities for improving the economic sector, a low-income scenario in rural areas, and limited utilisation of plentiful renewable energy sources cause a high degree of energy insecurity in rural Central Asia.

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